

Production of facing ceramic material using cullet

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Abstract. The research presents experimental results concerning the charge composition development for ceramics, used for cladding facades and basements of buildings and structures. The given composition is suggested to be based on the low plasticity clay as a basic component, which cannot be used to produce crackless, durable and frost resistant ceramics without introducing functional additives. The following functional additives were applied in the conducted experiments: boric acid, used as a fuse for the reduction of liquid phase sintering temperature and the increase of vitreous phase amount; various empties cullet, used as a fluxing and strengthening additive, which is the source of vitreous phase, forming the rigid frame of interconnected ceramic particles through a layer of vitreous phase. The research experiments stated that the highest compressive strength and frost resistance and the least water absorption can be achieved when 30 wt. % of colorless empties cullet and 2,5 wt.% of boric acid are introduced into the charge. Besides the research demonstrates the results of determining the dependence of bending strength, density, thermal conductivity, open and total porosity. The developed charge composition on the one hand stipulates the solution environmental and technical-economic problems of natural resources rational use and waste management, and on the other hand allows producing high quality facing ceramic products at a reduced cost and using low demand resources.

1 Introduction

Nowadays modern industry adheres and develops the tendency of using secondary resources in the production of various materials and products. Secondary resources are widely used at large-scale production facilities, where products do not require high quality basic operational properties.

Secondary resources application for the production processes is explained by the 2 groups of reasons. The first group refers to the ecological aspects and is connected with the accumulation rate reduction of waste, where secondary resources are obtained by recycling, and therefore prevent environmental pollution. The second group refers to the technical-economic reasons and deals with the possibility to reduce the production cost, due to the low cost of secondary resources and rational usage of all available resources like storage,

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disposal or incineration of waste, containing valuable production components, as it is economically feasible, since their application saves primary resources and expands the raw materials base.

Now secondary resources are widely used in the construction industry as fillers and various additives for the production of materials and products. Such prevalence is associated with the possibility of recycling large amounts of waste in the relatively simple technological processes. Herewith the most advanced technologies use waste and secondary resources, obtained from it, not only for the partial replacement of primary raw materials, but also as functional additives, influencing the materials and products structure and properties, thus improving their quality and expanding their application.

The research considers the possibility of producing facing ceramic material based on the low-plasticity clay with the addition empties cullet. Low plasticity clay is not widely used without the functional additives introduction, as it is characterized by poor strength, frost and crack resistance of products [1]. The application of empties cullet allows to produce a kind of composite material, where the vitreous phase formed during firing, serves as a binder for the ceramic particles thus reducing the disadvantages of the low-plasticity clays and uses them for producing high-quality products [2].

Previously the authors have conducted several researches for developing the charge composition based on low plasticity clay for producing construction materials [1, 3, 4] and developing the cullet disposal methods [2, 5, 6], including the joint application of the mentioned components in the compositions for producing facing materials [2, 5]. According to the research results it has been stated that the additives which are the source of vitreous phase, including the cullet, serve as flux-strengthening components, i.e. they reduce the temperature of ceramics liquid-phase sintering and increase its strength characteristics. Besides it has been determined that the combined introduction of a flux-strengthening additive and a fusing agent reduces the temperature of vitreous phase formation and self-glazing surface effect, moreover ceramic particles vitrification in depth occurs. As the research results show [2] boric acid is the best fusing agent.

It has been decided to replace window glass cullet by the empties cullet as it is the most widely spread glass waste due to bottles large scale production and comparatively short service life. The research objective was to define the type and the amount of the empties cullet for producing ceramic materials, which can be applied for the tiling of exterior building facades and cladding of basement structures.

2 Materials and Methods

The basic component of the charge composition is the low plasticity clay from the Suvorotskoye deposit in the Vladimir region possessing the following composition (wt. %): $\text{SiO}_2 = 67,5$; $\text{Al}_2\text{O}_3 = 10,75$; $\text{Fe}_2\text{O}_3 = 5,85$; $\text{CaO} = 2,8$; $\text{MgO} = 1,7$; $\text{K}_2\text{O} = 2,4$; $\text{Na}_2\text{O} = 0,7$. This clay refers to low plasticity type in compliance with Standard GOST 9169-75 as its plasticity index is 5,2 according to the standard method [1].

Different types of empties cullet were used as flux-strengthening additives corresponding to GOST R 52022-2003 requirements. The cullet type composition is given in the table.

Table 1. Empties cullet composition.

Cullet type	Oxides content, wt. %							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	Cr_2O_3
Colorless cullet	73,4	2,5	0,1	6,0	4,0	13,5	0,5	-
Green cullet	71,5	3,5	0,8	6,0	4,0	14,0	-	0,2
Brown cullet	71,4	3,3	0,5	6,0	4,0	14,0	-	-

The empties cullet given in the table refers to consumption waste, so glass works practically do not require it for recycling due the various composition of glass used by different producers.

Boric acid B 2-nd grade (GOST 18704-78) with basic substance weight of 98,6% has been used as a fusing agent, as it is a strong agent and melts at 170,9 °C [2] thus facilitating cullet melting at lower temperatures and stipulates ceramics liquid phase sintering.

The developed ceramic materials samples were made according to the technology of semidry pressing [1]. The clay was preliminary dried, reaching its constant weight, afterwards the clay and the cullet were crushed, subsequently particles fraction of max 0,63 mm was selected. Then the charge components were weighed according to the formula and first mixed dry and afterwards with 8 wt.% of water thus reaching homogeneous molding mass from which the samples were made under the pressure of 15MPa and fired at maximal temperature of 1050 °C. The temperature was selected according to the experiments with the window cullet [2]. The samples were made in three batches of three samples each.

To select the required cullet amount in the charge and to assess the compliance of the developed ceramics with the requirements for the facing materials, the following parameters were studied according to the standard methods: compression strength (σ_{cs} , MPa), bending strength (σ_{bs} , MPa), water absorption (W, %), frost resistance (F, cycles), density (ρ , kg/m³), thermal conductivity (λ , Wt/(m²·°C)), open (P_{opn} , %) and total (P_{tot} , %) porosity.

3 Results

The first experimental stage was devoted to the study of the impact of various empties cullet on the compression strength and water absorption, which are the basic properties for construction ceramics. The results of determining the samples properties are shown in Fig.1 and judging by the dependences nature they are similar to the previously researched window cullet [2].

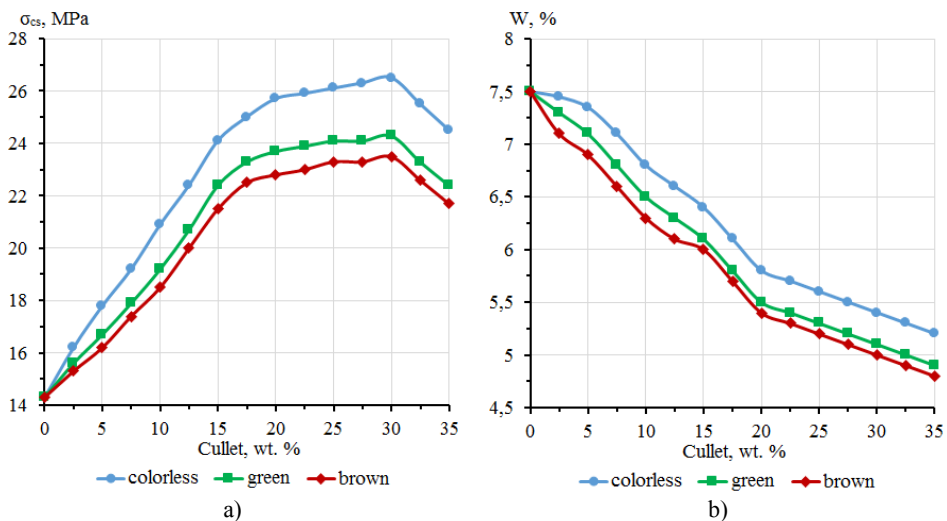


Fig. 1. Impact of compression strength (a) and water absorption (b) on cullet amount and type.

As the received data shows the intensive compression strength increase and water absorption reduction are observed for all types of cullet, alongside the increase of this component amount upto 20 wt.%. Such dependence might be connected with the fact that

the vitreous phase, formed during the firing at such amount of cullet, fills the pores and voids in the material thus forming a rigid structure of ceramics particles connected through the vitreous phase layers. The the cullet amounts from 20 to 30 wt.% insignificant compression strength and water absorption decrease occur, and at further amount increase over 30 wt.% the compression strength is gradually decreasing. Such effect can be explained by the vitreous phase layers thickening between ceramic particles, and consequently material compression strength becomes mostly dependent on vitreous phase properties, which are characterised by lower strength [2], connected with the defects of vitreous phase. The size and amount is growing alongside vitreous phase layers thickening and fragility. When over 30 wt.% of the vitreous phase is introduced, the products lose their shape and the samples edges melt.

The obtained data prove that the usage of colorless empties cullet promotes higher compression strength and lower water absorption. It depends on the inconsiderable amount of defects in the vitreous phase due to little thickness, and consequently its oxide composition impacts its strength considerably. As oxides MgO and CaO content is the same for all types of the considered empties cullet its impact can be neglected. The reference data states that Fe₂O₃ and Cr₂O₃ oxides do not affect the vitreous phase strength, SiO₂ and Al₂O₃ oxides increase the strength and the Na₂O and K₂O oxides decrease it. SiO₂ oxide greatly influences glass strength, its content in the colorless empties cullet is higher, but Al₂O₃ oxide affects slightly less and Na₂O oxide impact is even smaller, K₂O oxide impact is minimal [7]. Thus judging by the additivity it can be concluded that oxide composition of the colorless cullet provides maximal strength of the vitreous phase and all the developed ceramic materials as a whole.

At the second experimental stage boric acid was introduced into the charge in the amount of 2,5 wt.% and colorless empties cullet in the amount of 35 wt.%. The amount of boric acid is limited due to the previous researches, which showed that higher acid content insignificantly reduces strength characteristics [2] and toxic effect of this additive is possible, when introduced with the cullet.

As Figure 2 shows, joint introduction of the cullet and boric acid for compression strength causes similar dependence as observed in Figure 1, but compression strength is higher.

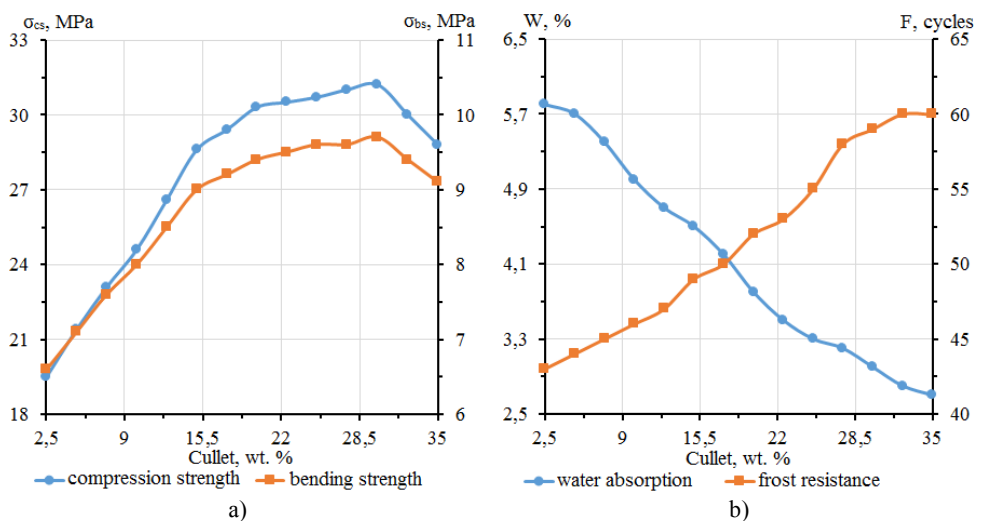


Fig. 2. Impact of compression and bending strength (a), water absorption and frost resistance (b) on the amount of colorless empties cullet at the additional introduction of 2,5 wt.% of boric acid.

It is connected with the fact that B_2O_3 oxide, formed from boric acid during the firing also increases vitreous phase strength [7] and increases its amount, thus facilitating ceramics liquid-phase sintering. The bending strength changes in the same dependence, when the compression strength reaches its highest value at the introduction of 30 wt.% of colorless empties cullet. Besides Figure 2 shows that water absorption reduction causes the increase of frost resistance of the developed ceramic material.

Figure 3 leads to the conclusion that joint introduction of colorless empties cullet and boric acid causes density and thermal conductivity increase, accompanied by the total and open porosity increase. Such changes of the properties are connected to the fact that vitreous phase fills pores and voids in the material, and in case of selfglazing effect, transfers most open pores into the closed ones. Porosity decrease, in its turn, increases the density and thermal resistance, and also decreases water absorption, which is proved by Figure 2.

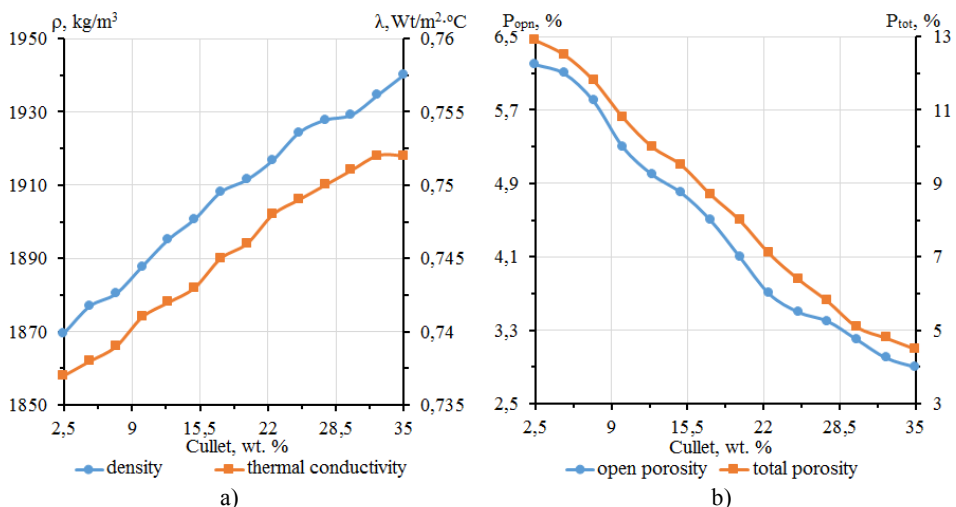


Fig. 3. Density and thermal conductivity dependence (a), open and total porosity (b) on the amount of colorless cullet at the additional introduction of 2,5 wt.% of boric acid.

Summarizing the data of Figures 2 and 3, and also considering that the developed ceramic material is to be used as a facing material, it has been decided to introduce boric acid in the amount of 2,5 wt.% and the cullet in the amount of 30 wt.% into the charge composition. Such amount of the colorless empties cullet provides maximal strength characteristics and also high frost resistance for the described composition.

4 Conclusions

Thus the conducted experiments have led to the development of the charge composition, based on low plasticity clay including 30 wt.% of colorless empties cullet as a flux-strengthening additive and 2,5 wt.% of boric acid. The given composition helps to produce high quality facing ceramic material using low plasticity clay, commonly not used in industry without introducing special additives, and the cullet, which is a waste and needs disposal. Consequently the application of the given charge composition allows to broaden raw materials base for the construction industry, decrease production cost of the products, based on the developed composition, and to reduce cullet waste piling rate in the environment.

The developed ceramic materials properties correspond to the construction materials requirements. The material strength is rather high, and water absorption is within the permissible limits for the outdoor facing construction materials (2-5%). Frost resistance exceeds 50 cycles and so it can be used both for facing facades, building and construction basement. Material density, thermal conductivity and porosity are average for the most construction materials. The possibility of achieving the self-glazing effect gives the advantages for using this material for the facing, as it additionally reduces water absorption and consequently increases frost resistance, besides it facilitates self-cleaning effect of the products under the rain or snow.

According to the research results the following conclusion can be made, the developed charge composition facilitates the solution of ecologic and technical-economic problems of the natural resources rational use and waste disposal, on the one hand, and allows to produce high quality facing ceramic products at lower cost and using low demand resources on the other.

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